SEARCHES FOR CHARGED HIGGS BOSONS AT LEP

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The four LEP experiments Aleph, Delphi, L3 and Opal updated their searches for pair production of charged Higgs bosons using more than 210 pb^{-1} luminosity collected per experiment in the year 2000. Combining it with previously collected data, a significant deviation from background (equivalent to 4.4 σ) is found by the L3 collaboration for low values of the branching ratio $\mathrm{H}^{\pm} \to \tau\nu$ around masses of about 68 GeV. This excess is however not seen by the other LEP collaborations and thus a lower limit on the charged Higgs mass is set at 78.5 GeV at 95% confidence level. All results reported here are still preliminary.

1 Theoretical Framework

In the Standard Model [1], the particle masses are generated through the coupling to the Higgs field. The Standard Model is minimal in the sense that it contains only one Higgs doublet which corresponds to four degrees of freedom. Three out of these area 'eaten up' by the longitudinal polarization states of the W and Z bosons, the remaining one is the physical Higgs field. However, there is no a priori reason why there should only be one such doublet. Two Higgs Doublet Models (2HDMs) [2] have eight degrees of freedom coming from the Higgs sector. Five of these correspond to the Higgs particles out of which two are the charged Higgs bosons H^+ and H^-. Their masses are predicted to be equal.

The charged Higgs sector of 2HDMs can be parameterized by the mass of the charged Higgs boson $m(\mathrm{H}^{\pm})$ and $\tan\beta$ which is the ratio of the vacuum expectation values of the two doublets.

Two types of 2HDMs are distinguished: The absence of flavor changing neutral currents puts a lower limit on the charged Higgs mass in e.g. type II models without further particle content [3], while type I models are much less restricted by experimental data. For low values of $\tan\beta$, the dominant decay modes are $\mathrm{H}^+ \to \mathrm{c}\bar{\mathrm{s}}$ and $\tau^+\nu_\tau$ (and charge conjugates) while for high values values of $\tan\beta$ the three body decay $\mathrm{H}^{\pm} \to \mathrm{W}^{\pm *}\mathrm{A}$ dominates. Of the LEP experiments, only Opal has performed a search for three body decays of charged Higgs bosons [4].

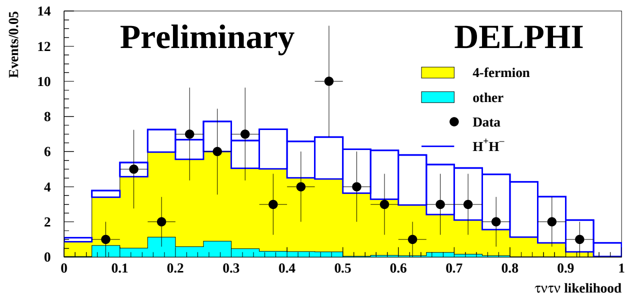

Figure 1: Likelihood variable of the DELPHI $\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ analysis. The shaded histograms represent the expected background, the open area is the signal expectation for a Higgs mass of 75 GeV (on top of the background). There is a good agreement between the observed data and the expected background.

This document reports on the searches for pair production of H^+ and H^- in $\mathrm{e}^+\mathrm{e}^-$ collisions at LEP. The dominant process is $\mathrm{e}^+\mathrm{e}^- \to \mathrm{Z}^*/\gamma^* \to \mathrm{H}^+\mathrm{H}^-$.

2 Experimental signatures and event selection

The branching ratio $\mathrm{BR}(\mathrm{H}^\pm \to \tau\nu)$ and the charged Higgs mass are not predicted by theory and therefore left as parameters of the search. It is assumed that $\mathrm{c\bar{s}}$ and $\tau\nu_\tau$ are only decay modes of the charged Higgs boson, leading to three different final states: $\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ (leptonic channel), $\mathrm{c\bar{s}}\tau^-\bar{\nu}_\tau$ [a] (semileptonic channel) and $\mathrm{c\bar{s}\bar{c}s}$ (hadronic channel).

Leptonic Channel: The leptonic channel is characterized by two acoplanar taus (electrons, muons or low multiplicity jets) and missing energy. No mass reconstruction is attempted since at least four neutrinos are present in the final state. The most important backgrounds are $\mathrm{e}^+\mathrm{e}^- \to \mathrm{W}^+\mathrm{W}^- \to \ell^+\nu\ell^-\bar{\nu}$, $\gamma\gamma$ collisions and $\mathrm{e}^+\mathrm{e}^- \to \tau\tau(\gamma)$ where the γ escapes detection.

For example, Delphi uses a likelihood method to discriminate between signal and background based on τ polarization variables and the polar angle of the τ decay products [5]. The distribution of the likelihood variable is shown in Figure 1. No significant excess is observed.

Semileptonic Channel: In this channel, high multiplicity events consistent with two jets plus an additional electron, muon or low multiplicity jet are selected. The events also must have a high amount of missing energy. The background is dominated by the process $\mathrm{e}^+\mathrm{e}^- \to \mathrm{W}^+\mathrm{W}^- \to \mathrm{q\bar{q}}\tau\nu$. As an example, Aleph uses linear discriminants in the analysis based on variables like the τ decay angle in the Higgs rest frame, τ polarization probability, Higgs production angle etc [6]. An example of the mass distribution after a cut on the discriminant is shown in Figure 2a. Data favor the background-only hypothesis.

Hadronic Channel: The signature of this channel is a four jet structure and no missing energy. The most important backgrounds are W pair and $\mathrm{q\bar{q}}$ production. For example, L3 uses in their four jet analysis (among other cuts) a neural network to discriminate $\mathrm{q\bar{q}}$ events [7]. The jets are grouped into pairs such that the probability of the pairs having equal mass is maximized. A cut on the Higgs production polar angle is applied to reduce the $\mathrm{W}^+\mathrm{W}^-$ background. The Higgs candidate mass distribution is shown in Figure 2b. A significant excess is observed at $m(\mathrm{H}^\pm) \approx 68$ GeV.

3 Combination of the Channels and LEP combination

Table 1 summarizes the observed and expected limits for fully hadronic and fully leptonic branching ratio as well as the observed limits independent of the branching ratio for the individual

[a] The charge conjugate reaction is implied throughout this letter

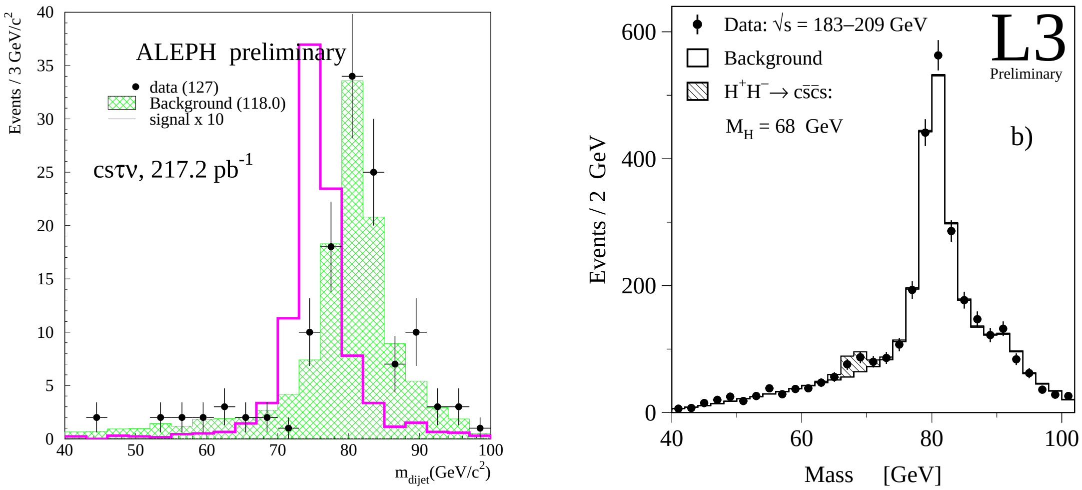

Figure 2: Left: Reconstructed Higgs candidate mass in the ALEPH $c\bar{s}\tau^-\bar{\nu}_\tau$ analysis. The hatched histogram is the expected background, the open histogram is the expectation from a charged Higgs signal enlarged by a factor of ten for a Higgs mass of 75 GeV. Data is in good agreement with the background expectation. Right: Reconstructed Higgs candidate mass in the L3 four jet analysis. The open histogram is the expected background, the hatched area is the expectation from a charged Higgs signal with a mass of 68 GeV (on top of the background).

Table 1: Observed (expected) lower limits on the charged Higgs mass in GeV at 95% confidence level. The limits are shown for the four LEP experiments and their combination.

	Aleph	Delphi	L3	Opal	LEP
$\mathrm{BR}(\mathrm{H}^\pm \to \tau\nu) = 0$	80.7 (78.1)	77.4 (77.0)	77.2 (77.1)	76.2 (77.1)	81.0 (80.1)
$\mathrm{BR}(\mathrm{H}^\pm \to \tau\nu) = 1$	83.4 (86.9)	85.4 (89.3)	84.9 (83.0)	84.5 (86.5)	90.0 (91.7)
lowest observed	78.0	73.8	67.1	72.2	78.5

experiments and their combination. Figure 3 shows the excluded region in the $m(\mathrm{H}^\pm)$ vs. $\mathrm{BR}(\mathrm{H}^\pm \to \tau\nu)$ plane for the combination of the four LEP experiments [8].

4 Summary

Searches for pair production of charged Higgs bosons in $\mathrm{e}^+\mathrm{e}^-$ collisions were performed by the four LEP experiments. A significant (4.4 σ deviation from the expected background) excess is observed around $m_{\mathrm{H}^\pm} \approx 68$ GeV in the L3 data over the last years, which is however not seen by the other LEP experiments. Work is continuing to better understand the nature of this excess and the difference between the observations of the four LEP experiments. Combining the L3 data with the other three LEP experiments, the deviation from background is significantly smaller than what one expects from a charged Higgs boson of mass 68 GeV, thus a lower limit of 78.5 GeV is set on $m(\mathrm{H}^\pm)$ at 95% confidence level. All results are still preliminary.

References

1. S.L. Glashow, *Nucl. Phys.* **22**, 579 (1961)
   S. Weinberg, *Phys. Rev. Lett.* **19**, 1264 (1967)
   A. Salam, "Elementary Particle Theory", ed. N. Svartholm, Stockholm, (Almquist and Wiksell, 1968), p.367

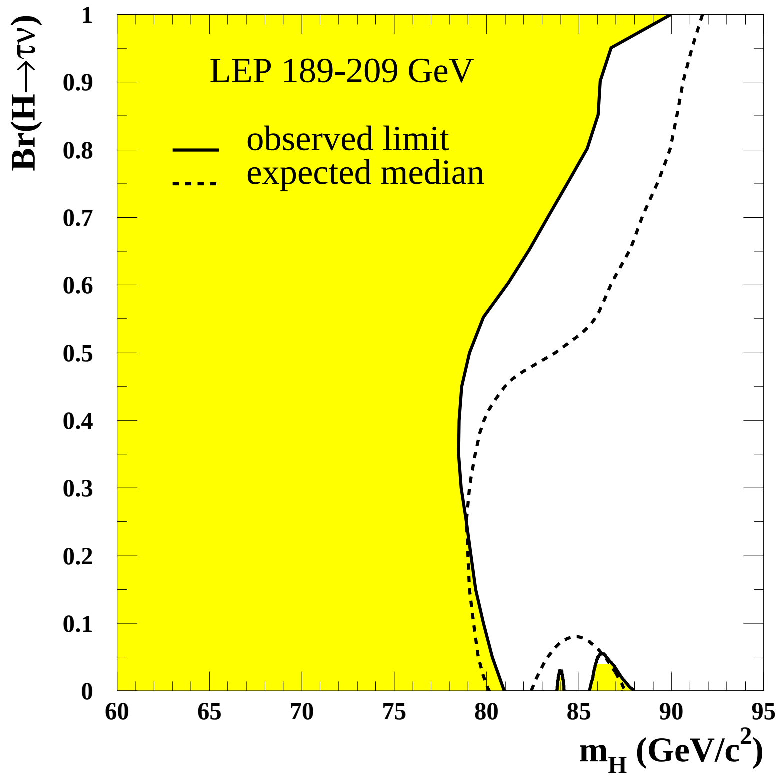

Figure 3: Excluded regions in the $m(\mathrm{H}^{\pm})$ vs. $\mathrm{BR}(\mathrm{H}^{\pm} \to \tau\nu)$ plane for the combination of the four LEP experiments (shaded region). The dashed line shows the median expected limit (from background processes).

2. S. Dawson *et al.*, "The Physics of the Higgs Bosons: Higgs Hunter's Guide", (Addison Wesley, 1989)
3. M. Ciuchini *et al.*, *Nucl. Phys.* B **527**, 1998 (21).
4. Opal Collaboration, "Searches for Higgs bosons in Extensions to the Standard Model in $\mathrm{e}^+\mathrm{e}^-$ Collisions at the Highest LEP Energies", OPAL Physics Note PN472
5. DELPHI Collaboration, "Search for Charged Higgs Bosons in $\mathrm{e}^+\mathrm{e}^-$ Collisions at $\sqrt{s} = 189 - 208$ GeV", DELPHI Conference Note DELPHI 2001-030 CONF 471
6. ALEPH Collaboration, "Update of the search for charged Higgs bosons for Year 2001 winter conferences" ALEPH Conference Note CONF/2001-013
7. L3 Collaboration, "Search for Charged Higgs bosons in $\mathrm{e}^+\mathrm{e}^-$ Collisions at Centre-of-Mass Energies up to 209 GeV", L3 Note 2643
8. The LEP working group for Higgs boson searches, "Search for Charged for Charged Higgs boson: Preliminary combined results using LEP data collected at energies up to 209 GeV", LHWG note 2001-1, `http://lephiggs.web.cern.ch/LEPHIGGS/papers/index.html` .